1. Introduction

1.1. General introduction

Food consumption generates the highest environmental impact per person. (Nijdam, 2005). Within the food domain, food products of animal origin have a particularly high environmental impact (Kramer, 2000; Goodland, 1997; Smil, 2002). Animal source foods – meat, milk and eggs – are a part of the human diet which provides metabolic energy, amino acids, vitamins and minerals. To produce animal source foods, vast amounts of natural resources are required, such as energy, land and water. However, the availability of natural resources is limited. Furthermore, natural resource use is associated with environmental degradation. Given this environmental impact and the increasing scarcity of natural resources, reduction in the consumption of such products is a challenge for the future. An often mentioned possible strategy to reduce the demands on natural resources of food production and consumption is moving to a more vegetarian diet. However, consumers will be very reluctant to give up the consumption of animal source foods (Hoogland, 2006). A consumer shift to a vegetarian diet is therefore not likely to occur in the near future. Forecasted demographic and socioeconomic transitions on a global level will result in an even greater demand for livestock products (Steinfeld, 2006). This makes the reduction challenge even more complex and urgent. According to the Food and Agriculture Organization of the United Nations (FAO), satisfying the increasing and changing demand for animal source foods while at the same time sustaining the natural resource base is one of the major challenges facing world agriculture (Steinfeld, 2006).

This thesis aims to provide an insight into the natural resource use of livestock products and to identify reduction options. There are, however, numerous livestock systems that produce an equally large number of livestock products and environmental impacts. Focus is therefore required. In the following we will define this study in greater detail.

1.2. Animal source food consumption

In prehistory humans acquired animal source foods through hunting, fishing and gathering. Approximately 11,000 years ago, humanity started to domesticate animals (Gupta, 2004). Domestication enabled the constant access to and full use of animal products and functions. In addition to meat, milk and eggs, domesticated animals – or livestock – also produce manure, wool, hair, feathers, leather and fur. Furthermore, livestock performs several functions: transport, draught, security, science, recreation, nature conservation and social and financial security. Depending on their environment and living conditions, the needs of different societies differ. Therefore, after domestication, people started to influence livestock

evolution to obtain breeds that better suited their needs. These needs evolved in changing socioeconomic conditions. Livestock production practices changed in response. The small-scale subsistence agriculture and related animal husbandry intended to ensure family nutrition developed into large-scale industrial farming to keep up with the increasing global demand for animal source foods.

Globally, animal source foods provide seventeen percent of dietary energy and thirty-five percent of dietary protein (Steinfeld, 2006). In developed countries these proportions are even higher, with animal source foods providing approximately thirty percent of dietary energy and sixty percent of dietary proteins (FAOSTATS). Furthermore, animal source foods are an important source of B vitamins, D vitamins, proteins, iron, sink, copper and selenium. Consumption of animal source foods is, however, not merely about obtaining nutrition. Other factors also influence our consumption behaviour of animal source foods. Price, sensory preferences, health, safety, ethics, religion, social aspects and environmental factors influence the type and amount of animal source foods consumed (Radder, 2005; Korthals, 2004). Sensory preferences such as taste, smell and texture are the most important determinants for Western consumers when buying animal source foods (Radder, 2005). Depending on a person's sensory preferences, purchasing behaviour differs.

In the last twenty to thirty years, various food scares have influenced consumer preferences and have drawn attention to health and food safety. Owing to media coverage, consumers have become aware of cholesterol, hormones, antibiotics, dioxins, avian influenza, salmonella, swine fever and Bovine Spongiform Encephalopathy (BSE). Research indicates that health and safety issues are the most important reason for consumers to reduce their consumption of meat (Verbeke, 2001; Gruner, 2006). The BSE scare for instance had a profound effect on EU meat consumption. Beef consumption dropped by twenty percent in 1996 immediately after the media coverage of the outbreak (Burton, 1996) and was down by forty percent in 2000 (Morgan, 2001). Over the ensuing months beef consumption recovered partially. However, it is estimated that beef consumption has structurally dropped by twelve percent (European Commission, 2005). As beef consumption dropped, consumption of pork and poultry increased considerably in the same period.

Tradition and social aspects also influence meat consumption behaviour. Western food cultures have traditionally viewed animal source foods as the central element of each meal (McCarthy, 2003; Gruner, 2006). Certain events are related to the consumption of specific animal source foods. For instance, turkey is consumed for Thanksgiving in the USA and many Christians consume eggs during Easter.

Animal welfare and the environment are issues that have barely affected consumers purchasing behaviour. (Harrington, 1991; Gruner, 2006). However, researchers expect that they will become increasingly important for consumers now because of greater attention in media and politics on these issues. (Verbeke, 1999; McCarthy, 2003)

1.3. Future transitions affecting the demand for animal source food

Large increases in the demand for animal source foods are projected to continue (Bradford, 1999; Popkins, 2001; Steinfeld, 2006). However, in developed countries

animal source food consumption has recently been increasingly influenced by concerns about health, environment, ethics, animal welfare and development, all of which combine to exert downward pressure on animal source food consumption (Steinfeld, 2006). The projected increase is mainly due to transitions in population size, economic growth and changing diets.

Growing populations
Currently, the global agricultural system is feeding a world population of 6.6 billion. Forecasts indicate that the world population will grow to approximately 9.2 billion by 2050 (United Nations, 2007). The demand for food will increase accordingly if all other factors stay unchanged.

Economic growth
A major determinant of the growth of animal source food demand is the growth in income. As incomes grow, expenditure on livestock products grows rapidly (Delgado, 1999). Therefore, a growing per capita income will result in a growing demand for animal source food. This effect is especially significant in low and middle-income countries where animal source food consumption is still low. In these countries the increase in meat consumption usually exceeds the increase in income. Forecasts produced by the World Bank show higher incomes for all regions and income groups. Incomes will increase in low and middle-income countries in particular.

Changing diets
As stated, diets transform as incomes rise and populations age. Other factors that affect changes in consumption patterns are urbanization and global eating. In the previous century populations moved away from rural areas and into cities. Currently, half the world's population lives in cities. This development will continue over the coming decades. People in cities have on average a lower rate of physical activity and therefore lower nutritional needs. This effect reduces the increase in animal source food consumption. However, urban people also have different consumption patterns. They consume fewer staples, eat out more frequently and consume larger quantities of ready-to-heat and ready-to-cook meals and more snacks. Therefore, urbanization has an influence on the position and function of animal source foods (Steinfeld, 2006; Rae, 1998).
People from industrialized nations consume particularly large amounts of food products that are produced in different countries. This global eating is possible due to technological advances. Technological advances in preservation allow food to be eaten long after it is grown and harvested. Technological advances in transportation – such as aircraft, trucks, ships etc. – allow food grown in one place to be consumed 'fresh' on the other side of the world. Technological advances in agriculture have resulted in a greater diversity of food products and lower relative prices. This has led to more varied and richer consumption patterns. These consumption patterns are less monotonous and contain more added fats, sugar, alcohol and animal source foods.

Increase in population and the per capita increase in consumption will result in massive increases in animal source food consumption. Delgado (1999) estimate that the annual world growth rate of animal source food consumption will be three percent for meat and 1.5 percent for milk. It is expected that in coming decades this growth will require a 'livestock revolution' (Delgado, 1999). To meet the projected demands will require investments in agricultural production research and development and the implementation of policies that encourage feed production and feed conversion efficiency. Protecting the environment will also be essential.

1.4. Dutch animal source food production system

As defined by Peet (1992) 'A system is a whole that cannot be divided into independent parts. Each part has properties it loses when separated from the system and visa versa every system has some essential properties that its parts do not have.' The most important features of systems are relationships and variety. The animal source food system is the entire food production and consumption system from primary production to food consumption, including related branches that supply resources, goods and services, and that process waste. The animal source food system is a subsystem of the natural system that depends on natural resources. For instance, without the direct input of natural resources such as solar energy, sufficient food production would not be possible. The animal source food system has many elements and thus many relationships. System analysis comprises research into the interaction between such relationships with the aim of understanding how various systems function and how they interact and subsequently affect their related environments. This thesis predominately focuses on the Dutch animal source food production system.

The Dutch animal source food production system is part of a global system. Large quantities of food end-products and raw materials are imported and exported. Owing to globalization, it is difficult to determine the boundaries of the Dutch animal source food production system. Does it comprise all animal source food produced in the Netherlands or all food produced for Dutch consumers or all animal source food produced by the Dutch? The latter refers to Dutch food companies that own farms, aquaculture facilities and food processing factories in countries other than the Netherlands. This thesis focuses on the overall system surrounding animals kept in the Netherlands. The origin of the resources such as feed,[1] agro-chemicals etc., needed to raise livestock can be anywhere in the world.

Figure 1.1 shows a simplified outline of the animal source food production system. Crop cultivation produces the crops used by the feed industry. The feed from the feed industry is fed to livestock to produce eggs, raw milk and livestock which are processed by the food industry into animal source foods (e.g. sausages and dairy products). The animal source foods are consumed by consumers.

[1] In this thesis a distinction is made between food and feed. Foods are consumed by humans while feeds are consumed by livestock. Animal source foods are, therefore, foods of livestock origin such as meat, milk and eggs, and livestock feed is for instance the roughage and concentrates fed to livestock.

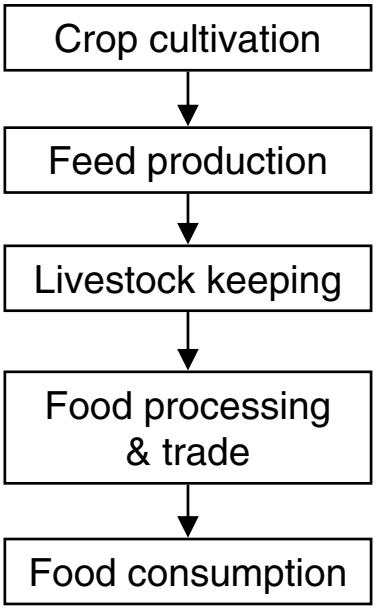

Figure 1.1 Schematic representation of the animal source food system

The Netherlands produces approximately one percent of the world's animal source foods. Pigs, chicken and cattle are quantitatively the most important livestock in the Netherlands. These animals produce different kinds of food products. Cattle produce beef and milk, chickens produce meat and eggs, and pigs produce pork. In the Netherlands in 2006, four million cattle, eleven million pigs, over one hundred million chickens and five million animals of other species produced three billion kilograms of meat, over ten billion eggs and eleven billion kilograms of milk (LEI/CBS, 2007). However, less than half of this production is consumed within the Netherlands. The remainder is exported mainly to other EU countries. To feed all the livestock in the Netherlands requires over twenty-one billion kilograms of feed. The bulk of the raw materials required to produce feed is imported. (LEI/CBS, 2007).

In the Netherlands livestock can be kept according to different types of management schemes. Examples of management schemes are conventional, ecological, free-range, organic and organic-dynamic. There are differences within these management scheme types. For instance, free-range can be indoors, outdoors, partly outdoors, outdoors on grass and with or without an enhanced cage. Owing to this large variety, a common simplified distinction is drawn between intensive and extensive production. Intensive production is an agricultural production system which is not land bound, meaning that the required crops for feed are not grown on the same farm. Furthermore, intensive production has a

relative high input per hectare of materials such as pesticides, antibiotics, fertilizer and water. On the other hand, intensive production has a high yield per hectare or animal. Intensive livestock production is associated with industrial or conventional farming. Extensive farming means that all or a large part of the feed crops are cultivated on the same farm; the input of materials is relatively low compared to intensive farming, as is usually its yield. Extensive farming usually entails the non-conventional management types such as ecological and organic. In 2004 2.5 percent of livestock farms in the Netherlands were classified as ecological or organic (Statistics Netherlands, 2009). In this thesis we focus preliminarily on intensive farming.[2] This includes conventional dairy farming. Although dairy farming in the Netherlands uses grassland, a large part of the fodder required is purchased and significant amounts of fertilizer and antibiotics are used.

1.5. Environmental issues related to animal source food production

Numerous environmental impacts are directly or indirectly related to animal source food production. In addition to its consumption of finite natural resources, animal source food production contributes to climate change by emitting greenhouse gases; eutrophication through the loss of nutrients; acidification by emitting NH_x; pollution through the use of pesticides, antibiotics and herbicides; loss of biodiversity through deforestation, pollution and monoculture agriculture; and various other kinds of environmental degradation of air, land and water. Furthermore, the environmental impact of livestock production can have effects at different levels: local, regional and global. Climate change affects the entire world while eutrophication has an effect at a local or regional level. Because animal source food production has an impact on almost all aspects of the environment (Steinfeld, 2006), a large number of indicators are required to monitor all these aspects. These indicators generate large amounts of data that often provide no additional information on environmental sustainability (Gerbens, 2003). Food production requires three essential finite natural resources: arable land, fresh water and energy. Therefore, Gerbens (2003) proposed using three global environmental performance indicators – energy use, land use and water use – to understand environmental impacts and interactions with the food production system (Gerbens, 2003). Furthermore, energy use, land use and water use are closely related to the most important environmental problems.

The use of energy from fossil fuels is the most important source of anthropogenic greenhouse gases. Greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) contribute to climate change, currently perceived as the most important environmental problem.

Agriculture accounts for the largest proportion of human land use, seventy percent of which is required by livestock, or in other words thirty percent of the land surface of the Earth (Steinfeld, 2006). Furthermore, food production has to compete for land with other anthropogenic land users such as urban expansion. This limits the available arable land. Therefore, in the near future more food has to be produced on less available land. Already, the land required for animal source food production

[2] The terms conventional, industrial and intensive are used interchangeably in this thesis.

is a key factor in environmental problems. For instance, land degradation such as deforestation, desiccation and soil loss, has been directly linked to the land required for animal source food production (Steinfeld, 2006).
Freshwater is scarce in many world regions, therefore, to serve the water needs of a growing world population with a diminishing freshwater supply is a major challenge for the coming century (Rosegrant, 2002). Agriculture is the largest consumer of fresh water (Turner, 2004). The animal source food production system uses water for drinking and servicing the animals, irrigation of crops and for production processes. Reducing the use of the natural resources required for livestock production will have a positive effect on most environmental impacts – local, regional or global – related to animal source food production. According to the FAO 'responsible management of natural resources is the key to attaining sustainable agricultural and rural development' (Steinfeld, 2006).

1.6. Natural resource use

The animal source food production system requires direct or indirect natural resources such as energy, water and land. Although all production steps require natural resources, their respective shares differ greatly. For instance, food processing plants require land for buildings. Due to the large amount of animal source food products processed and their relatively small footprint, the contribution of food processing plants to the total land use is negligible. Figure 1.2 shows the significance of energy, land and water to each production step. In this thesis the focus is predominantly on energy and land use.

Production chain	Energy	Land	Water
Crop cultivation	X	X	X
Feed production	X		
Livestock keeping	X	X	X
Food processing & trade	X		X
Food consumption	X		X

Figure 1.2 Inventory of the production steps within the animal source food production system which contribute significantly to the use of natural resources

1.7. Scope of the thesis

Human activities generally require natural resources to meet their needs. Production of animal source food is not an exception. The analysis in the preceding sections shows the following:

- Land, water and energy are the primary inputs for animal source food production and the use of these resources generates all kinds of environmental impacts
- Current and future developments in food demand require more natural resources while simultaneously stretching the environmental capacity of the planet to its limits

Therefore, in terms of sustainability and equity to current and future societies, the natural resource requirements of animal source food production have to be reduced. One possibility is to reduce the current heavy animal source food consumption in Western societies to subsistence levels. Owing to low consumer willingness, the reduction of consumption for environmental reasons is, however, limited (Hoogland, 2006). Furthermore, the financial and political interests of animal source food production are tremendous. This makes an imposed reduction unlikely. An under-explored option is the possibility of optimizing the natural resource use of the animal source food production system.

This thesis aims at providing options for reduction of the consumption of natural resources by animal source food production and consumption. To formulate options for reducing the natural resource use of animal source food production systems, insight into how these systems function and knowledge of their natural resource use is required. The research goals of the thesis originate from this understanding.

- ❖ To gain insight into the natural resource use of animal source food production systems.

- ❖ To identify possibilities and options to reduce the natural resource use of animal source food production.

Assessing all the animal source food production systems in the world is not possible, owing to time and data availability constraints. It is also not necessary for understanding reduction options and their implications. All animal source food production systems require the same commodities, use roughly the same types of animals and function according to the same principle – the conversion of vegetable products into livestock. Therefore, this thesis uses the Dutch animal source food production system as a case study. The computer model MODIAS (Elferink, 2009) was developed to determine natural resource use and to assess reduction options.
The findings of this thesis can be used to determine the effect of transitions in population size, population composition, economic growth and changing diets on the environmental impact of animal source food production and consumption. Furthermore, the findings can be used to analyse criteria for a more environmentally friendly food production and consumption system.

1.8. Structure of the thesis

The land requirements of beef, chicken and pork are determined in Chapter 2. Furthermore, the effect of system changes on the land requirement for meat is analyzed. The various factors that affect land requirements for meat production are identified.

Chapter 3 analyses the energy use in the animal source food production systems for chicken, pork, eggs and milk. Results are compared on the basis of fresh weight and on their nutritional value as protein sources. The chapter identifies multiple options for reducing the energy use of animal source food products.

A case study of how a change in policy (the banning of meat and bone meal in feed as a result of BSE) can affect the environmental impact of animal source food production is presented in Chapter 4. It also shows the global scale of the animal source food system and the trade-offs that can occur.

The relationship between food consumption and the availability of human-inedible residues, feed composition and the environmental impact of meat is analysed in Chapter 5. This chapter shows the possible effect dietary changes can have on the environmental impact of meat.

Chapter 6 compares organic and industrial pork production with respect to their natural resource use for different system settings. This chapter shows the factors that determine the natural resource use of feed.

Finally, Chapter 7 provides an overview of the natural resource use of the various animal source food production systems. It discusses the various reduction options identified in this thesis and presents the main conclusions.